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Common Path Interferometer Using Fresnel Zone Plates*†

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M. V. R. K. MURTY
Institute of Optics, University of Rochester, Rochester, New York
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A new kind of interferometer for testing any unit magnification optical system is described. The method utilizes diffraction beam splitting and involves the use of two identical Fresnel zone plates, one by the side of the other. The interference patterns obtained are easy to interpret because the fringes are the loci of equal optical path difference of the wavefront under test with respect to a reference sphere.

INTRODUCTION

IN interferometers of the Twyman type,[1] the two interfering beams are separated widely and are such that the effect of any air turbulence and vibrations is considerable unless suitable precautions are taken. Also, the reference wavefront is obtained separately from a plane mirror in one arm of the interferometer. Thus, the beam splitter and the reference plane mirror should be of the same size as the optics under test in the conventional type of the Twyman interferometer. By the use of diverging light in both beams, the size of the beam splitter could be made small, but still the reference concave mirror should be as big as the optics under test.[2,3] To avoid these limitations of the Twyman interferometer for testing, especially large optics, a new approach is introduced by some workers, particularly Burch[4,5] and Dyson.[6,7] Burch uses two identical scatter plates, thus using scattering as a means of beam splitting. Dyson uses a composite lens of glass and Iceland spar having two different focal lengths for the ordinary ray and the extraordinary ray, thus using polarizing as a means of beam splitting. One of the beams is made to focus on a small area of the optics under test while the other beam is made to fill the whole aperture. The focused beam is thus free from aberration and hence serves as the reference beam. The beam that fills the aperture contains the wavefront aberrations. The word "common path interferometer" is coined by Dyson for these interferometers because both beams essentially travel in the same direction, one inside the other.

INTERFEROMETER

The purpose of this paper is to show that one could use diffraction as a means of beam splitting and construct a common path interferometer for testing large optics. The scheme utilizes the diffraction properties of Fresnel zone plates and Fig. 1 shows how one could test a concave spherical mirror at its center of curvature. The light from the point source S is focused by the lens L on the mirror M under test. The Fresnel zone plate P_1 diffracts part of the light and this fills the aperture of the mirror M. The portion of the light which is not diffracted from its original course is brought to a focus upon the mirror M by the illuminating lens. The light from the mirror M is returned to the second Fresnel zone plate P_2 and now the direct beam is diffracted and the diffracted beam is passed through undeviated. The two Fresnel zone plates are identical and mounted one by the side of the other in one plane. The assembly could be moved on a three coordinate mount so that one could explore the region near the center of curvature of the mirror. Figures 2–4 show photographs of the fringes obtained with this setup of a good concave spherical mirror. The interpretation of these fringes is direct and each fringe is the locus of constant optical path difference of the wavefront under test with the reference wavefront. When the plane of zone plates passes through the center of curvature of the mirror, the two wavefronts have same curvature. Thus the fringes obtained are straight due to tilt between these wavefronts. The tilt is obtained by moving the assembly of the zone plates in their own plane. In addition to lateral displacement, if there is a longitudinal displacement of the plane of zone plates with respect to the center of curvature, the fringes obtained are circular with their center displaced laterally. The bright central spot, which is worthy of note, appears simply to be due

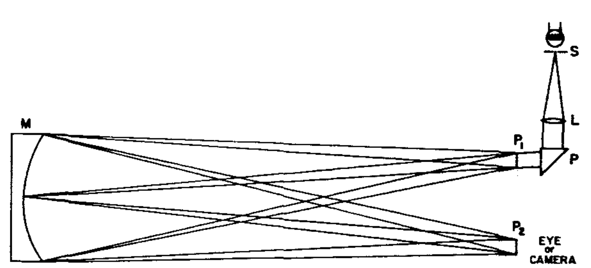

FIG. 1. Schematic arrangement for testing a concave mirror with the two identical Fresnel zone plates. M is the concave mirror; P_1,P_2 are identical Fresnel zone plates; S is the point source of light with a filter; L, lens to focus the image of S on the mirror M; and P, right-angle prism to deviate the light by 90° for convenience.

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[1] For more information on the Twyman interferometer, see, for instance, C. Candler, *Modern Interferometers* (Hilger and Watts Ltd., Hilger Division, London, 1951), pp. 135–190.
[2] See reference 1, p. 170, Fig. 7.15.
[3] W. Weinstein, J. Sci. Instr. **28**, 351 (1951).
[4] J. M. Burch, Nature **171**, 889 (1953).
[5] J. M. Burch, J. Opt. Soc. Am. **52**, 600 (1962) (abstract only).
[6] J. Dyson, J. Opt. Soc. Am. **47**, 386 (1957).
[7] J. Dyson, Appendix B, "Interferometers," in J. B. Strong, *Concepts of Classical Optics* (W. H. Freeman and Company, San Francisco, California 1958), pp. 377–392.

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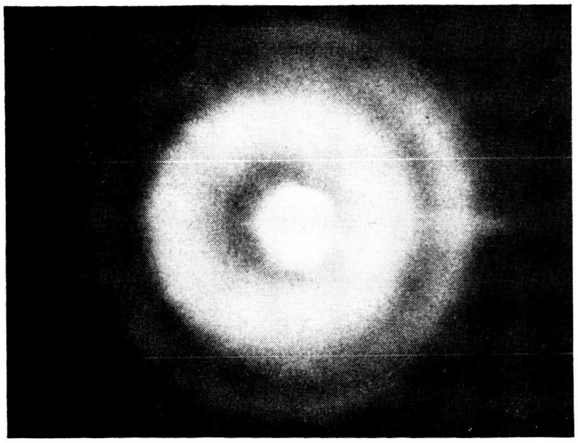

FIG. 2. Photograph of the fringes obtained when the plane of zone plates is slightly outside of the center of curvature with no lateral displacement.

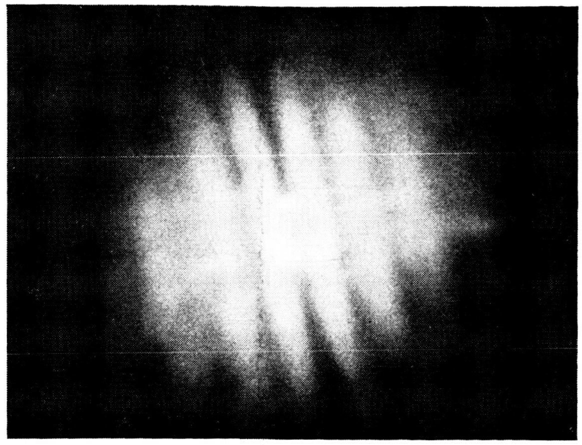

FIG. 4. Photograph of the fringes obtained when the plane of zone plates is passing through the center of curvature with a small lateral displacement. This is the normal position one should look for when attempting to detect small deviations from a spherical surface.

to that part of the beam of light which is not diffracted by either plate plus a portion of the light which is diffracted by both plates. The pattern of interest here is a result of interference between the beam diffracted only by the first plate and the beam diffracted only by the second plate.

Since the path differences between the reference beam and the aberrated beam are small, the fringes are easily obtained by using a bright point source of white light. If one wants to test a lens, a plane mirror behind it is all that is needed to obtain the setup similar to one in Fig. 1.

The fringes in Figs. 2–4 were obtained by using Fresnel zone plates of 3-mm aperture and a nominal 52-mm primary focal length. This means that the relative aperture covered by this setup is about $F/17$. In order to cover a larger relative aperture one has to have Fresnel zone plates with shorter primary focal lengths with about the same convenient 3-mm-diam aperture. This means that the number of zones should be increased and also that the spacing at the edges of the zone plate should be finer. One may derive a simple rule as follows. Let d be the spacing at the edge of the zone plate of diam D and let f be the primary focal length of

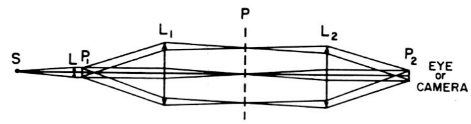

FIG. 5. Schematic arrangement of a common-path interferometer for use in various applications. L_1,L_2 are lenses of equal focal length spaced with their foci coinciding; P is the common focal region where one inserts the specimen; P_1,P_2 are identical Fresnel zone plates; L is the lens to collimate the light from a point source so that the direct light is focused in a small area of the specimen; and S, point source of light with a filter.

the zone plate. Then one has for incident collimated light of mean wavelength λ,

$$D/2f \approx \lambda/d,$$

or

$$d \approx 2\lambda\ (f \text{ number}). \tag{1}$$

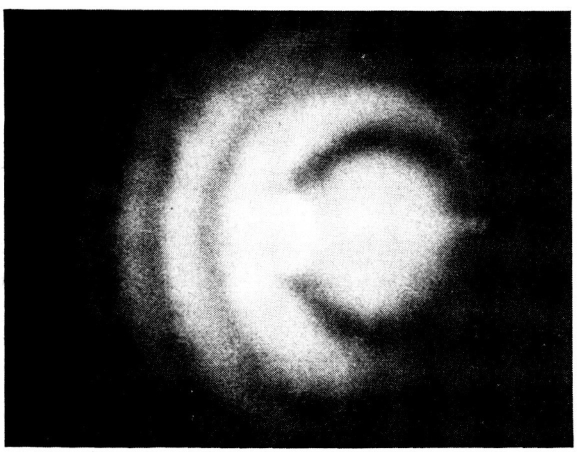

FIG. 3. Same as the one in Fig. 2 except for a small lateral displacement.

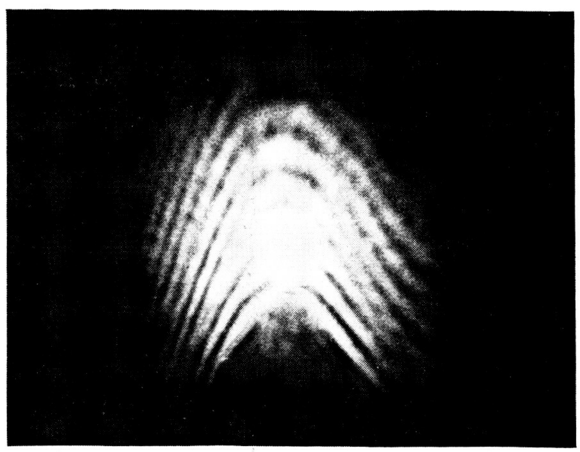

FIG. 6. Photograph of fringes obtained when a hot soldering iron is placed in the region P shown in Fig. 5.

If one takes $\lambda=0.5\ \mu$, one has the simple rule that d is (f number) μ. Thus to test $F/4$ optics one has to have Fresnel zone plates with 4-μ spacing at the edges and so on. This is not impossible and we are able to obtain, in our preliminary experiments, resolutions better than that on thin-emulsion high-resolution plates.

OTHER POSSIBLE APPLICATIONS

Figure 5 shows a system in which two zone plates are identical at the foci of the lenses of equal focal length. The lenses are spaced such that their foci coincide. Collimated light is sent through the first zone plate P_1 and the direct light is focused at the common focus of the lenses and emerges collimated again after passing through the second lens L_2. This direct light is diffracted through the second zone plate P_2. The diffracted light from the first zone plate P_1 fills the aperture of the first lens L_1 and passes through the space between the lenses essentially collimated and is focused by the second lens L_2 on the second zone plate P_2 and this is passed through undeviated. Thus the region normal to the axis at the common focus of the lenses is passed through a very narrow region by the direct light and a large surrounding region by the diffracted light. If this region contains optical path differences either due to change of index or thickness or both, the interference between the direct and diffracted beams gives this information directly. Figure 6 shows a photograph of the fringe system obtained using the arrangement of Fig. 5 where a hot soldering iron is placed at the common focus of the two lenses. The arrangement could be used for wind tunnel experiments.

The arrangement is exactly the same for applications in interference microscopy of thin transmitting specimens. Figure 7 shows a photograph of a thin mica sheet with microsteps in it. For reflective specimens the scheme shown in Fig. 8 could be used.

At first one may think that simple diffraction gratings of equally spaced straight rulings or concentric rulings would be sufficient for the above-mentioned schemes. However, if one looks carefully, one finds that in order to fill the whole aperture with diffracted light one has to use Fresnel zone plates.

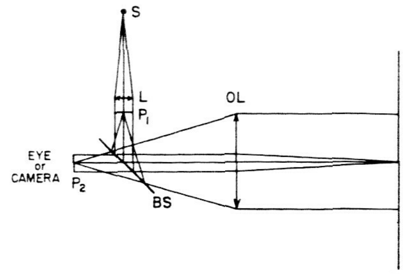

FIG. 8. Schematic arrangement of the common-path interferometer useful for reflecting specimens. OL is the objective lens; RS, reflecting specimen; BS, beam splitter; P_1,P_2 are identical Fresnel zone plates; L is the lens to collimate the light from a point source so that the direct light is focused on the specimen; S, the point source of light with a filter.

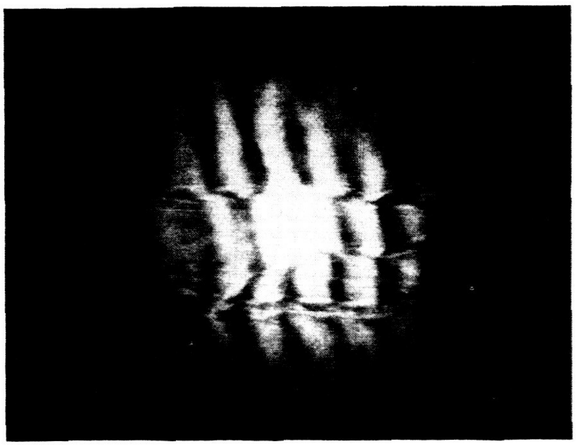

FIG. 7. Photograph of fringes obtained when a thin mica sheet with microsteps in it is placed in the region P shown in Fig. 5.